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THE USE OF AERIAL PHOTOGRAPHY FOR DEVELOPMENT OF FUEL LOADING PREDICTION MODELS WITHIN THREE COVER TYPES IN THE JEMEZ AND SANGRE DE CRISTO MOUNTAINS OF NEW MEXICO

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ABSTRACT

Fuel load prediction equations that make use of aerial photographs were developed for Mixed Conifer, Ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.) and Pinyon-Juniper (*Pinus edulis* Engelm.) (*Juniperus monosperma* Engelm.) cover types from one time measurements made in the Santa Fe watershed located in the Sangre de Cristo Mountains of northern New Mexico. Additional fuel sampling occurred at Los Alamos National Laboratory (LANL) located in the Jemez Mountains of Northern New Mexico. Use of these or similar prediction equations may be limited to certain regions and community types that exhibit similar regional characteristics such as terrain, soils, and weather conditions. This was demonstrated when the prediction equations developed from the Santa Fe watershed data set was applied to both the watershed and LANL data sets for comparison. The results of the watershed data set were favorable and exhibited a high degree of relative accuracy. The results from the LANL data set did not share the same degree of accuracy but rather exhibited a high degree of error. This may strongly indicate possible limitations for applied use of prediction equations of this nature to regions that exhibit similar characteristics such as terrain, soils and weather. Small difference in site characteristics, such as the amount of precipitation or evapotranspiration that occurs, may have an effect on the amount of bio-mass or fuels generated on one site that is not reflected on another site even though they may be within a few miles of each other.

Applied use of the prediction equations required less time than traditional fuel sampling performed on-site, but suffered from a loss of accuracy. It is strongly suggested that additional study of this method be undertaken to generate more accurate and reliable equations. Hopefully, more accurate equations may augment existing fuel sampling techniques and be put to practical use in the future for fire planning purposes.

INTRODUCTION

Forest fires were a regular phenomenon in what is now the western United States before the arrival of the Europeans. Active fire suppression of the last 100 years has promoted an unnatural amount of forest fuels (Dodge 1972). Accumulation of fuels is now showing a profound effect on forest conditions. Low intensity fires that would periodically reduce fuel loads have turned into infrequent high intensity fires that are stand-replacing events on a catastrophic level, such as occurred in Yellowstone National Park in 1987 (Wright 1988).

Research for the estimation of fuel loading in forest conditions has been performed for forest cover types common to the Jemez mountains in north-central New Mexico. Previous work (Kittredge 1944; Cable 1958; Ffolliot *et al.* 1968; Ffoliot *et al.* 1977) has shown that strong correlations exist between certain stand characteristics and forest fuel loads of woody material. Of the stand characteristics examined, stand basal area (BA) was the most consistent stand characteristic for estimating fuel loads. Crown diameter or percent crown cover are stand characteristics commonly measured using aerial photography. Remote sensing (ie satellite imagery and aerial photography) has been used for such purposes as predicting the fuel model (Oswald *et al.* 1999) and fire danger rating by evaluating the cover vegetation of an area (Jain *et al.* 1996). Aerial photograph based fuel predictions may provide rapid assessment of fuels and the sampling of large areas quickly, or useful for areas that are difficult to access.

The objectives of this research project were to determine if a relationship exists between forest fuels measured on the ground and overstory conditions (stand composition, basal area, and crown cover) of Pinyon-Juniper, Ponderosa Pine, and Mixed Conifer cover types commonly found within the Jemez and Sangre de Cristo Mountains of north-central New Mexico, then develop fuel load prediction equations based on results of field sampling of fuel loads and overstory conditions measured from on-site and overstory conditions measured from aerial photographs.

Sackett (1979) attempted to develop a reliable method of predicting fuel loadings of ponderosa pine and mixed conifer forests of the Southwest. Research sites were selected from undisturbed public lands in Arizona, New Mexico, and southern Colorado. Results of their research did not find reliable statistical relationships for predicting fuel loading by stand characteristics, including basal area, with the lack of a positive correlation that could be attributed to variation in stand characteristics. This study may indicate that fuel predictions may be limited to stands with more uniform growth.

Scientists in India developed a method that makes use of Geographic Information Systems (GIS) to prioritize fire risk areas (Deeming *et al.* 1978). Land cover information was derived from the Linear Image Self Scanning data of the Indian Remote Sensing Satellite IRS IB. Topographical maps and ground data were used to verify and support GIS data entry. Field sampling of fuel loads were used as criterion for deciding the ratings of different vegetation classes from the National Fire Danger Rating System. Fuel conditions and physical features were used as factors that influence fire. These factors were correlated to areas of previous fire occurrences to evaluate sites for potential fire risks. From 17 sites that were previously burned, 42 percent of the total burned area fell into the high and moderately high risk categories, while 40 percent fell in the moderate risk categories. Results from this test showed a high amount of agreement between predicted risk areas and affected areas (Jain *et al*. 1996).

There is very little information on the use of aerial photography for the purpose of fuel load predictions (Ryan, K. C. Pers. Comm. 1998). However, the use of aerial photography for the purpose of determining fuel models was reported by Oswald *et al.* (1999). From air photos, stand and overstory characteristics such as stand composition, basal area, and crown cover were estimated. A photo guide of fuel models (Reeves 1988) was used to compare and match the stand characteristics to the fuel model. Plots were measured on the ground and corresponding points matched to black and white, panchromatic 1:80,000 scale photos. Test sites were field checked on the ground. Results of the field checking produced an accuracy of 84.6%. These sites that were misclassified were, partly because of loss of detail from the photo scale. Use of air photos for fuel model prediction appears to be an effective technique when using stand characteristics such as composition, basal area, and crown closure and fuel characteristics.

METHODS

Different systems were used for determining the location of the 116 research plots for the two study sites. On the Santa Fe National Forest, U.S. Forest Service personnel identified 60 plot locations. The 60 plots were divided equally into three elevational groupings; low (>8600 ft), medium (8600 ft-9560 ft), and high (+9000 ft). Each elevation group of 20 plots was broken into five clusters of four plots, one plot per cardinal direction. Prospective plot locations were established on a topographic map of the research area. For the LANL research area a total of 56 sample plots were subjectively chosen. The plot locations were established to represent the pinyon-juniper woodlands, ponderosa pine forests and mixed conifer forests within LANL.

Each sample site was evaluated for homogeneity with respect to vegetation structure, soils and topography within a 105 ft by 105 ft (32 m by 32 m) square, and the area surrounding the square. The center of each site was marked and the UTM coordinates of the center were recorded with a global positioning system (GPS) unit. The slope and aspect of each plot was recorded using a Suunto clinometer and compass respectively.

From the center of each sample site, a series of 50 ft (15.2 m) radiating lines were established. A compass was used to determine true north (magnetic declination 11° East) for the initial line location. Fifteen subsequent lines were placed at 22.5 degree intervals in a clockwise direction radiating outward from the center point. To avoid excessive sampling at the center location, the odd numbered lines were started at 10 ft (3 m) and even numbered lines at 30 ft (10 m) from the center point.

Down Woody Fuels

Fuel sampling followed the procedure described by Brown *et al.* (1982). To facilitate subsequent analysis, these fuels were subdivided into 1 hour (<0.25 in (< 0.6 cm)), 10 hour (0.25-1 in (0.6- 2.5 cm)), 100 hour (1-3 in (2.6-7.6 cm)) and 1000 hour fuels (>3 in (> 7.6 cm)).

Litter and Vegetation Samples

Litter samples were collected within four-1ft x 2 ft (0.3 m x 0.6 m) rectangular plots along each sample line. Plots were located at 6 ft (5 m) and 8 ft (7 m) along each line; the remaining plots were located 4 ft (1.2 m) off the lines from the first two plots. Once plot placement was completed, the litter and understory vegetation was independently rated within each rectangular plot. The rectangle with the greatest amount of vegetation was exhaustively sampled and the material placed in a labeled bag for drying and weighing. The plant biomass of the remaining rectangles was estimated as a percentage of the sampled rectangle. To obtain litter samples, the above process was repeated in the same rectangles for vegetation. All estimated litter and vegetation percentages were recorded on data sheets.

Tree Measurements

Trees were sampled in 0.25 acre (0.1 ha) square plots which were situated over the plot centers. Within each plot, all trees were recorded by species, total height and diameter. The diameters of trees less than 1 in (2.54 cm) in diameter at 4.5 ft (1.4 m) in height were measured at ground level; all others were measured at dbh. Total heights were measured to the nearest ft (m) and diameters to the nearest inch (cm). Canopy densities of each plot were measured using a crown densiometer at the center of each 0.25 acre (0.1 ha) plot. Four readings (facing the four cardinal directions) were made and an average canopy density was determined and recorded.

Laboratory Measurements

The litter and vegetation samples were dried for 24 hours at 65 °C, weighed and the data entered into spreadsheet files. The estimated litter and vegetation samples were converted to weight measures from the dry weight data. All field data were entered into spreadsheet files. Fuel loads and number of trees were transformed to a per-acre (ha) basis. These data were summarized for each of the three communities of interest (Pinyon-Juniper, Ponderosa pine, and Mixed Conifer).

Color aerial photographs (1:15840 scale) of the Santa Fe Watershed study area were obtained from the U. S. Forest Service. Study site locations were identified on the air photos and crown density was for each site measured using visual density guides. Crown density from the air photos was compared to crown density measured in the field for accuracy. Providing a sufficiently accurate match between on-site crown density and remote crown density was found, correlations between woody fuels on the ground and crown density were examined with the intent of generating mathematical models for predicting fuel load. Aerial photographs of the LANL study plots were not obtained due to security issues and difficulty in purchasing the photos.

Statistical Analysis

Statistical Analysis was performed on the data using the PROC ANOVA procedures in SAS Version 6 (SAS Institute, Inc. 1990). An alpha value of $p=0.1$ was used to determine if significant differences existed among surface fuels and overstory characteristics; basal area, percent crown cover and percent crown cover measured from aerial photographs, between three community types from the two research areas sampled. Prediction equations were developed using the PROC REG procedures in SAS Version 6. The prediction equations were derived from overstory characteristics and total fuel loads by community type.

RESULTS

Basal Area

When basal area was used as the independent variable for statistical analysis of the woody fuels, the mixed conifer cover type had the most variables that exhibited significance (Table 1).

Crown cover and total fuels for the Santa Fe Watershed (SFWS) and combined watershed and LANL (SFWS/LANL) data sets were highly significant ($p \leq .001$). Other variables such as 1000-Hour Rotten fuels, Litter and Vegetation were also significant to highly significant in the same two data sets. This pattern is not reflected in the LANL data set. With exception of percent crown cover, the correlations had no significant pattern between data sets, even though some variables showed significance, notably most in the LANL data set (Table 2). The Pinyon-Juniper cover type (Table 3) exhibited a pattern of significance between the LANL and combined data set for the total fuels and 1000 Hour Rotten fuels variable. The 10 Hour fuels of the watershed data set was the only other variable that exhibited significance for this cover type.

Table 1. ANOVA correlation coefficients for significance when basal area was used as the independent variable for statistical analysis of the Mixed Conifer cover type.

	Mixed Conifer		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Crown Cover	.0001	.0001	.1584
Total Fuels	.0005	.0001	.1233
1 Hr fuels	.0791	.1519	.6268
10 Hr fuels	.0705	.1400	.6742
100 Hr fuels	.2654	.2611	.4468
1000 Hr Sound	.0439	.0299	.0046
1000 Hr Rotten	.0011	.0001	.0709
Litter	.0013	.0014	.1805
Vegetation	.0085	.0029	.6364

Table 2. ANOVA correlation coefficients for significance when basal area was used as the independent variable for statistical analysis of the Ponderosa pine cover type.

	Ponderosa pine		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Crown Cover	.7880	.0240	.0324
Total Fuels	.5648	.6163	.8684
1 Hr fuels	.2643	.4717	.0171
10 Hr fuels	.2530	.2464	.3604
100 Hr fuels	.6357	.6992	.2013
1000 Hr Sound	.6977	.1515	.0422
1000 Hr Rotten	.4241	.5660	.8684
Litter	.5887	.8288	.6932
Vegetation	.9655	.0774	.3087

Table 3. ANOVA correlation coefficients for significance when basal area was used as the independent variable for statistical analysis of the Pinyon-Juniper cover type.

	Pinyon-Juniper		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Crown Cover	.6667	.1657	.5165
Total Fuels	*	.0024	.0001
1 Hr fuels	.6667	.8590	.7170
10 Hr fuels	.0001	.8089	.3286
100 Hr fuels	*	.6677	.2643
1000 Hr Sound	*	.6308	.7170
1000 Hr Rotten	*	.0823	.0075
Litter	.6667	.4263	.2720
Vegetation	*	.7780	.2630

SFWS = Santa Fe Watershed data set
SFWS/LANL = Santa Fe Watershed and Los Alamos National Laboratory combined data set
LANL = Los Alamos National Laboratory data set
* = Insufficient data to perform analysis

Crown Cover from On-site

When percent crown cover was used as the independent variable for statistical analysis, the Mixed Conifer cover type had the most variables that exhibited significance (Table 4). Yet, no single variable exhibited significance across the data sets.
Basal area, 10 Hour fuels and Vegetation show significance between the combined and SFWS data sets, while the litter was the only variable to show significance between the combined and LANL data sets. Litter was also the only variable of significance in the LANL data set. The Ponderosa pine cover type had no variables that exhibited significance across all three data sets and only one variable, basal area, that had significance in the combined and LANL data sets (Table 5). Most of the variables that exhibited significance for this cover type were found in the LANL data set. Only one variable, Litter, exhibited significance for the SFWS data set. The Pinyon-Juniper cover type had three variables that exhibited significance in two of the data sets (Table 6). The 1-Hour fuels were the only variable with significance for the watershed and LANL data sets, while Litter and Vegetation exhibited significance between the combined and LANL data sets.
A pattern may be observed between cover types. In general, the Mixed Conifer cover type consistently exhibits significance in the SFWS data set and the Ponderosa pine cover type consistently exhibits significance in the LANL data set. The Pinyon-Juniper cover type exhibited no such consistency.

Table 4. ANOVA correlation coefficients for significance when percent crown cover from on-site measurements was used as the independent variable for statistical analysis of the Mixed Conifer cover type.

	Mixed Conifer		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Basal Area	.0301	.0277	.1526
Total Fuels	.0568	.1077	.6088
1 Hr fuels	.8167	.7892	.9521
10 Hr fuels	.0442	.0903	.6726
100 Hr fuels	.4245	.6000	.9839
1000 Hr Sound	.8754	.9643	.5523
1000 Hr Rotten	.0253	.1097	.3862
Litter	.2088	.0390	.0583
Vegetation	.0207	.0108	.5387

Table 5. ANOVA correlation coefficients for significance when percent crown cover from on-site measurements was used as the independent variable for statistical analysis of the Ponderosa pine cover type.

	Ponderosa pine		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Basal Area	.1532	.0138	.0293
Total Fuels	.9780	.5708	.0999
1 Hr fuels	.4770	.4671	.0888
10 Hr fuels	.6579	.1155	.0690
100 Hr fuels	.8847	.4958	.3778
1000 Hr Sound	.2470	.7286	.8688
1000 Hr Rotten	.8495	.5296	.0999
Litter	.0677	.1008	.3008
Vegetation	.4743	.0550	.4360

Table 6. ANOVA correlation coefficients for significance when percent crown cover from on-site measurements was used as the independent variable for statistical analysis of the Pinyon-Juniper cover type.

	Pinyon-Juniper		
Dependent Variable	SFWS	SFWS/ LANL	LANL
Basal Area	.6667	.3206	.1616
Total Fuels	*	.2040	.1616
1 Hr fuels	.0001	.4781	.0674
10 Hr fuels	.6667	.1793	.0895
100 Hr fuels	*	.7844	.6459
1000 Hr Sound	*	.4591	.6248
1000 Hr Rotten	*	.5959	.5860
Litter	.6667	.0594	.0537
Vegetation	*	.0266	.0592

Crown Cover from Aerial Photographs

Only the SFWS data set was used in the analysis procedure when statistical analysis was performed with percent crown cover measured from aerial photographs (Table 7). Air photos were not available for the LANL research area. Results of statistical analysis determined that few variables exhibited significance.

Table 7. ANOVA correlation coefficients for significance when percent crown cover measured from air photos was used as the independent variable for statistical analysis.

Dependent Variable	Mixed Conifer	Ponderosa pine	Pinyon-Juniper
Basal Area	.1729	.8691	.6667
Crown Cover	.0188	.6106	.6667
Total Fuels	.5406	.8806	*
1 Hr fuels	.8611	.9915	.6667
10 Hr fuels	.0213	.3574	.6667
100 Hr fuels	.0984	.4098	*
1000 Hr Sound	.2731	.6065	*
1000 Hr Rotten	.6589	.9002	*
Litter	.6744	.8689	.0001
Vegetation	.1811	.0009	*

* = Insufficient data to perform analysis

The Mixed Conifer cover type had the most variables that were significant; crown cover, 10 Hour and 100 Hour Fuels. The Ponderosa Pine cover type had one variable ,Vegetation, which was highly significant. The Pinyon-Juniper cover type had one variable ,Litter, which was also highly significant. No variables were significant across all three cover types. Specifically, analysis indicated that there was no significant correlation between total fuels and percent crown cover measured from air photos, which was the aim of this research project.

Prediction Equations

Forest fuel prediction equation models were developed for on-site percent crown cover derived from air photos, on-site percent crown cover and on-site stand basal area from each research plot. Prediction models were grouped by community type; Mixed Conifer, Ponderosa pine and Pinyon-Juniper.

Mixed Conifer

$Y = 29.281748+(\text{photo})*(0.192076)$ $r^2 = 0.0135$ (1)

$Y = -7.868660+(\text{crown})*(0.822022)$ $r^2 = 0.2369$ (2)

$Y = 2.450100+(\text{BA})*(0.258805)$ $r^2 = 0.3779$ (3)

Ponderosa pine

$Y = 8.577295+(\text{photo})*(-0.130975)$ $r^2 = 0.0185$ (4)

$Y = 22.751839+(\text{crown})*(-0.130975)$ $r^2 = 0.0101$ (5)

$Y = 14.878755+(\text{BA})*(0.023149)$ $r^2 = 0.0014$ (6)

Pinyon-Juniper

$Y = 7.457143+(\text{photo})*(-0.055429)$ $r^2 = 0.5614$ (7)

$Y = 5.630000+(\text{crown})*(-0.008667)$ $r^2 = 0.0176$ (8)

$Y = 3.562368+(\text{BA})*(0.047932)$ $r^2 = 0.9572$ (9)

Where:

Y = Total fuel yield in tons per acre

Photo = Crown cover (%) measured from aerial photograph

Crown = Crown cover (%) measured from the ground

Basal = Basal area (sqft/acre) of the stand, measured from the ground.

The dependent variables chosen for the development of the prediction equations were those most likely to be used for field applications. Equation models were developed from the Santa Fe watershed data set. The equations are based on total fuel loads (tons per acre) and were tested against the original data set to determine relative accuracy with the sum of deviation for each cover type and corresponding dependent variable (Table 8). The equations were then tested against the LANL data set to compare accuracy (Table 9).

Table 8. Results of percent sums of deviation from true fuel load in tons per acre of the prediction equations when used on the watershed data set.

Dependent Variable	Mixed Conifer	Ponderosa pine	Pinyon-Juniper
Photo	8.2	11.9	-0.2
Crown	181.1	-5.6	0.0
Basal Area	78.3	873.1	-0.3

The air photo percent crown cover analysis resulted with a moderate to high degree of accuracy for all community types (equations 1, 4 and 7). Both the percent crown cover (equations 2, 5 and 8) and stand basal area (equations 3, 6 and 9) analysis resulted with a high to low degree of accuracy.

Table 9. Results of percent sums of deviation from true fuel load in tons per acre of the prediction equations when used on the Los Alamos National Laboratory data set.

Dependent Variable	Mixed Conifer	Ponderosa pine	Pinyon-Juniper
Crown	505.9	-2244.1	-904.5
Basal Area	232.6	861.6	993.4

Use of the watershed equations on the LANL data set proved to be unreliable which may indicate that equations may not be suitable for use outside of the immediate region form which they were developed.

DISCUSSION

When basal area was used as the independent variable for analysis certain patterns in the data became visible. Crown cover exhibited a highly significant correlation for the Mixed Conifer cover type, a significant correlation for the Ponderosa pine cover type, and no significant correlation for the Pinyon-Juniper cover type. Total fuels, a sum of all woody and non-woody fuel components, exhibited a highly significant correlation for the Mixed Conifer cover type, with exception to the LANL data set, no significant correlation for the Ponderosa pine cover type and a significant correlation for the Pinyon-Juniper cover type with exception to the SFWS data set. For the Mixed Conifer cover type, all woody fuels in the SFWS data set, with the exception of 100 Hr fuels, were significant while only the 1000 Hr sound and 1000 Hr rotten fuels were significant in the combined and LANL data sets. For the Ponderosa pine cover type only the 1 Hr and 1000 Hr sound fuels from the LANL data set exhibited significance. For the Pinyon-Juniper cover type the 10 Hr fuels from the SFWS and 1000 Hr rotten fuels from both the combined and LANL data sets exhibited significance. Non-woody fuels, Litter and Vegetation, had significant correlation in both the SFWS and combined data sets for the Mixed Conifer cover type. The Ponderosa pine cover type only exhibited significance with vegetation in the combined data set. There was no apparent significance with non-woody fuels in the Pinyon-Juniper cover type. The results of the Mixed Conifer and Ponderosa pine correlations may be explained by the variation in stand composition. Lack of significant results in the Pinyon-Juniper cover type may be explained by a lack of data for the SFWS as only 3 plots were collected for this cover type in the SFWS research area.

When percent crown cover from on-site measurements was used as the independent variable for analysis a different set of patterns emerge. Basal area exhibited significant correlation for the Mixed Conifer cover type, with exception to the LANL data set, significant correlation for the Ponderosa pine cover type, with exception to the SFWS and no significant correlation for the Pinyon-Juniper cover type. Total fuels exhibited a significant correlation for the Mixed Conifer cover type in only the SFWS data set and in only the LANL data set for the Ponderosa pine cover type. There were no significant correlations in the Pinyon-Juniper cover type for any of the three data sets. Woody fuels exhibited a significant correlation in the Mixed Conifer cover type for only the 10 Hr and 1000 Hr Rotten fuels in the SFWS data set and 10 Hr fuels in the combined data set. Woody fuels exhibited a significant correlation in the Ponderosa pine cover type for only the 1 Hr, 10Hr, and 1000 Hr Rotten fuels in the LANL data set. Only the 1 Hr fuels of the SFWS and LANL data sets and 10 Hr fuels of the LANL data set exhibited significance for the Pinyon-Juniper cover type. Non-woody fuels exhibited significant correlations in almost all data sets for the three cover types. Greater variation may be expected when comparing crown cover to surface fuels than when comparing basal area to the same conditions.

When percent crown cover measured from air photos was used as the independent variable for analysis, very few variables exhibited significance. Crown cover, 10 Hr and 1000 Hr fuels were significant for the Mixed Conifer cover type, Vegetation for the Ponderosa pine cover type and Litter for the Pinyon-Juniper cover type.

The significance, or lack of significance, may be explained by the reduced amount of variation discovered in the Mixed Conifer cover type data and the increased amount of variation found in the Ponderosa pine cover type data. The variation in the Ponderosa pine cover type data may be due to the presence of other species within the Ponderosa pine sample plots, which may have resulted in misclassification of the sample plots. The presence of other species within the overstory plot that were not accounted for may have had a significant impact on the fuel complex. The process used in this study classified plots by the majority of species present in the sample plot. This may be the cause of some of the error found in the prediction equations. This may be avoided if a sub-classification process were used to identify sample plots by gradients of composition. Insufficient data may be responsible for the lack of correlation for many of the variables in the Pinyon-Juniper cover type.

When the prediction equations, developed from the percent crown cover derived from air photos, on-site percent crown cover and on-site stand basal area, were tested against the SFWS data set and then against the LANL data set, a stark contrast was revealed. For the SFWS data set the air photo prediction equations were relatively accurate for all three cover types, while the on-site percent crown cover prediction equations were accurate for the Ponderosa pine and Pinyon-Juniper cover types, and on-site basal area prediction equations were accurate for only the Pinyon-Juniper cover type. The same prediction equations for on-site percent cover and on-site basal area were applied to the LANL data set. Both sets of equations resulted in grossly inaccurate predictions for all three cover types. This might indicate that such prediction equations are not suitable for use outside of the immediate region from which they are developed. Conditions sampled in the LANL research area could have been altered over time due to land management by LANL personnel, thereby creating a distinctly different fuel and stand complex even if the present stand conditions appeared similar. Further research in the use of prediction equations and remote sensing might identify some of the errors experienced in this project and result in more accurate prediction equations.

CONCLUSIONS

The use of air photos at a scale of 1:15840 for predicting fuel loads appears to be a feasible method. This method does have certain limitations. There was a noticeable lack of accuracy when performing this method. This may be unavoidable when considering the inherent variation between forest stands within the same species and the factors involved; for example interpreter introduced error and image clarity. If the prediction models are used, the photo interpreter needs to be familiar with the community types involved in such a way as to be able to properly identify them from a photograph. It is essential for the proper use of the prediction equations. This method is flexible with regard to photo type, scale and age, as long as the photos available are recent and have the appropriate scale to determine community type and percent crown cover. The photos used in this study were natural color 1:15840 scale and were sufficient for the task. Black and white photos may be useful for this procedure, as they tend to have more clarity than color photos, but may prove more difficult to determine species composition of a cover type with the lack of color. Color infrared photos may be useful as well by making available more information about a site. It could be possible to better identify species type by reflectance signature as well as provide additional information such as moisture stress, which could be useful for fire planning. Different photo scales may also prove useful as long as the photos used exhibit enough detail to accurately make percent crown cover measurements. If larger photo scales are used less area will be included in the photo but image clarity would increase, which is important to the data gathering process. The benefit of using a large scale photo with this procedure would be that large areas might be sampled rapidly. As the photo scale is reduced the photo images will decrease in clarity but cover more area. Use of smaller scale photos may increase the accuracy of percent crown measurements but more photos would be necessary to sample the same area. Gathering the necessary information to use the prediction equations takes very little time and there is no need for special equipment. All that is necessary are air photos, a visual density guide to determine percent crown cover, and a pocket stereoscope. One of the clear benefits of using prediction equations for estimating fuel loads is that it is much faster than gathering data from the field.

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